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VALIDATION OF THE ATMO-STREET AIR QUALITY MODEL USING A LARGE-SCALE MEASUREMENT DATA SET OVER WARSAW, POLAND

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Abstract: Urban areas in Poland face severe air quality challenges due to high population density and elevated pollutant levels. The residential sector is a primary contributor to particulate matter emissions, with transportation also playing a significant role. This project aims to enhance the ATMO-Street model chain by integrating the GEM-AQ model for background concentration data alongside the IFDM and OSPM street-canyon module. Executed for Warsaw in 2022, the model incorporates residential emissions, traffic emissions (exhaust, non-exhaust, and resuspension), and background concentration data. Validation relied on nine reference stations and Airly sensors from 31 devices, cross-checked with reference stations. A sensitivity study compared the model with and without traffic emissions, and with and without residential emissions. Running the model without residential emissions led to underestimation of PM10 and PM2.5 concentrations, especially at stations away from street canyons. Introducing residential emissions improved concentrations at background stations and all sensor locations with overestimations in winter, and underestimations at traffic stations for PM10, indicating an overestimation of residential emissions in background locations and an underestimation of traffic emissions, mainly resuspension emissions, at traffic stations.

Key words: Street level modelling, Dispersion modelling, Particulate Matters, Sensors, Model validation

INTRODUCTION

Warsaw, the capital of Poland, with a population of about 1.8 million, lies in the Mazovian Voivodeship in central-eastern Poland. Its temperate climate is influenced by both maritime and continental factors, with prevailing winds usually from the west and southwest. In 2022, average wind speeds in Mazovia ranged from 10 to 13 m/s, while temperatures remained between 9 and 10°C. The region's air quality is significantly impacted by human activities, including household heating, transportation, and industrial operations. In Warsaw, vehicle traffic and fuel consumption are significant contributors to pollution, exacerbated by rapid economic growth since the early 1990s. The city's vehicle fleet has expanded dramatically, with registered vehicles increasing by nearly 58% between 1995 and 2011 to approximately 1.2 million vehicles, according to the Central Statistical Office.

METHODOLOGY

ATMO-Street model chain

The ATMO-Street model chain (Hooyberghs et al., 2022) was applied to 2022 with a unique set-up to simulate PM2.5 and PM10 concentrations at the street level in Warsaw, Poland. This integrated model chain is designed to assess air quality on a local scale, encompassing variations in both regional and local sources of air pollution (Lefebvre et al., 2013). The Atmo-street model chain comprises three main components: the land-use-based interpolation model RIO, which determines background concentrations (Janssen et al., 2008); the bi-gaussian plume dispersion model IFDM, which considers the influence of local emissions from traffic and industry (Lefebvre et al., 2011); and the street-canyon module OSPM, responsible for calculating the in-street increment due to street-canyon effects (Berkowicz, 2000). However, in this study, the GEM-AQ model (Kaminski et al., 2008) was utilized in place of the RIO model.

The model chain computes hourly concentrations at various receptors distributed irregularly, which are then transformed into a consistent grid with a 10-meter resolution. A comprehensive description of the model's elements will be provided in the following section.

Emission data

In this study, point emissions from the residential sector were calculated in Poland's National Database Management Unit with the bottom-up approach. This approach takes into account detailed input data such as location, area, number of stories, heating degree days (HDD), fuel composition, building age, and access to the heat distribution networks (Gawuc et al., 2021).

Traffic emissions were meticulously analyzed using diverse data sources, including the Yanosik app, national inventory, statistical data from traffic models, and population density statistics. The Yanosik app provided detailed user and speed data for all roads, which was synchronized with Open Street Maps' road network geometry. Exhaust emissions and non-exhaust emissions from tire, brake, and road wear were considered in emission estimates, however, road dust resuspension was overlooked, leading to underestimated PM10 emissions, particularly in dry conditions. To address this, resuspension emissions were separately calculated using the VEIN model (Ibarra-Espinosa et al., 2018), which factors in the number of vehicles, road length, and emission factors from paved roads specified in AP42 13.2.1[1] . The spatial distribution of PM2.5 and PM10 emissions from linear sources has been illustrated in Figure 1. Table 1 presents the sum of the emissions of PM10, and PM2.5 attributed to both traffic and residential sectors.

Tabel 1. Emission sum (Mg/yr) by sector in the domain of the study for the year 2022

Sector	PM10	PM2.5
Residential	3486.9	3171.2
Traffic	889.9	532.2
Resuspension	317.7	76.9

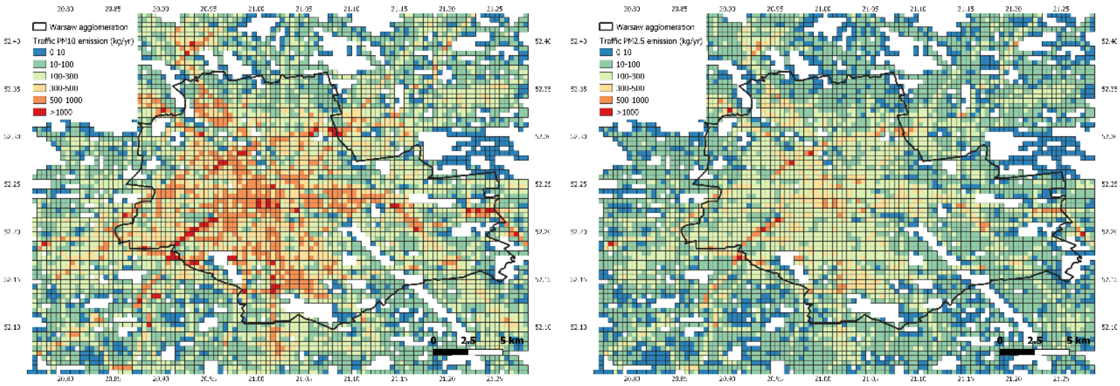

Figure 1. The spatial distribution of (right) PM10 (kg/yr) and (left) PM2.5(kg/yr) in the domain of the study from the line sources (traffic and resuspension emission)

Background concentration data

Background concentrations were simulated through the GEM-AQ –an online chemical transport model (CTM), which offers a unified approach for integrating meteorological and air quality components within the atmospheric system (Kaminski et al., 2008). GEM-AQ generated hourly concentrations for PM2.5 and PM10 on the original computation grid with a resolution of 2.5km (0.025 degrees). Emission data from the industrial and non-industrial combustion plants, road transport, and residential heating were included in the background concentration model.

Measurements

Measurement data for PM2.5 and PM10 were obtained from 9 stations provided by the Chief Inspectorate of Environmental Protection (GIOŚ) as reference stations and from sensor data provided by Airly[2] from 31 distinct locations situated within the study's domain. These sensor placements were carefully selected, with a preference for locations proximate to street canyons. The location of these stations and sensors is shown in Figure 5.

[1] https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-section-1321-paved-roads-related-information-0

[2] https://airly.org/map/pl/

RESULTS

This study aims to assess the model's performance in predicting concentration gradients at high spatial resolution by incorporating different emission sources into the model chain. The results taking into account different sectors will be analysed in this section.

Validation

Scatter plots of observed data against modelled data from PM10 and PM2.5 are shown in Figure 2. Figure shows the validation plots for the model chain which has all the incorporated emission sources (traffic, residential heating, and resuspension of the road dust).

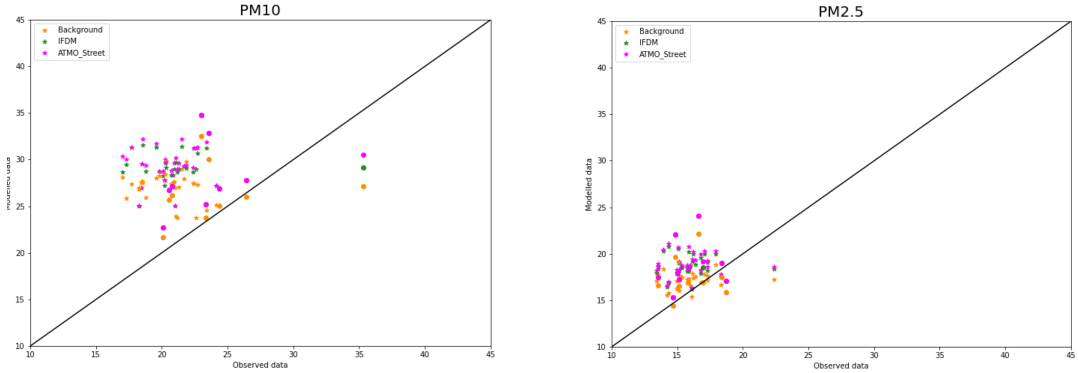

Figure 2. Validation scatter plot for annual average (left) PM10 and (right) PM2.5 concentration in Warsaw

Validating street canyon contributions in this configuration proves challenging. Scatter plots in Figure 2 reveal an overestimation of PM10 at background stations and sensor locations distant from street canyons, contrasting with underestimations at traffic stations within street canyons. This suggests underestimated resuspension in street canyons, where coarse PM10 particles are re-emitted. Residential emissions appear higher in locations away from street canyons, while traffic emissions are underestimated within canyons. PM2.5 overestimation, though less pronounced, persists. Notably, PM2.5 concentrations at street canyon reference stations show promise. These scatter plots reflect annual average concentrations, necessitating deeper analysis of monthly profiles. Figure 3 illustrates PM2.5 monthly profiles, revealing a strong correlation with observations at traffic stations, but with slight overestimations in winter. March exhibits significant PM10 underestimation, likely due to underestimated resuspension emissions during the month's dry conditions (based on the GIOŚ report in 2023[3]). Overall, scatter plots highlight widespread PM10 overestimation across sensor locations.

Temporal profiles

The monthly profiles of sensors, whether within or outside street canyons, consistently reveal systematic overestimations in PM10 concentrations across all months, with more pronounced overestimations during winter. For PM2.5, overestimations are primarily observed in winter, particularly at traffic stations, while the model demonstrates better performance in summer, attributed to minimal resuspension contributions to PM2.5 concentrations. It's important to note that Airly sensors are calibrated with the nearest reference station, introducing bias correction that mitigates the street canyon effect on PM10 and PM2.5 concentrations. This is especially relevant considering there is only one reference traffic station in Warsaw.

Sector contribution

Analyzing sector contributions to PM10 and PM2.5 concentrations in Warsaw revealed key trends: residential heating significantly affects concentrations in winter, while the traffic sector dominates in summer, especially in street canyon locations like Aleja Jerezolomskie. Figure 4 depicts sector contributions and background concentrations for January and July, emphasizing the significant influence of background concentrations. Total local contribution to PM10 and PM2.5 concentrations peaks at around 30% within the study area. Conversely, traffic contribution peaks at 17% in street canyons, particularly in the city center, where buildings are mainly connected to the gas heating network, intensifying traffic's impact on PM10 and PM2.5 concentrations (Figure 5).

[3] Annual assessment of air quality in the Mazowieckie Voivodeship Province, report for 2022 – in Polish

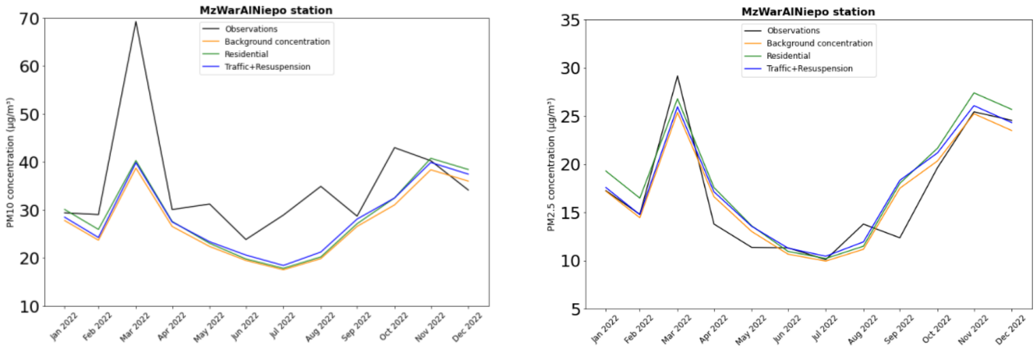

Figure 3- Monthly profiles of (right) PM10 and (left) PM2.5 in the reference traffic station

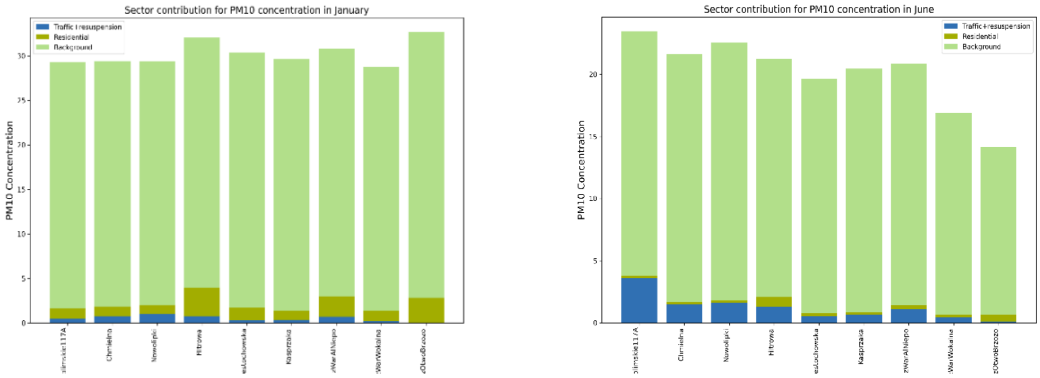

Figure 4- Local contribution to PM10 concentration in different sensor and reference station locations

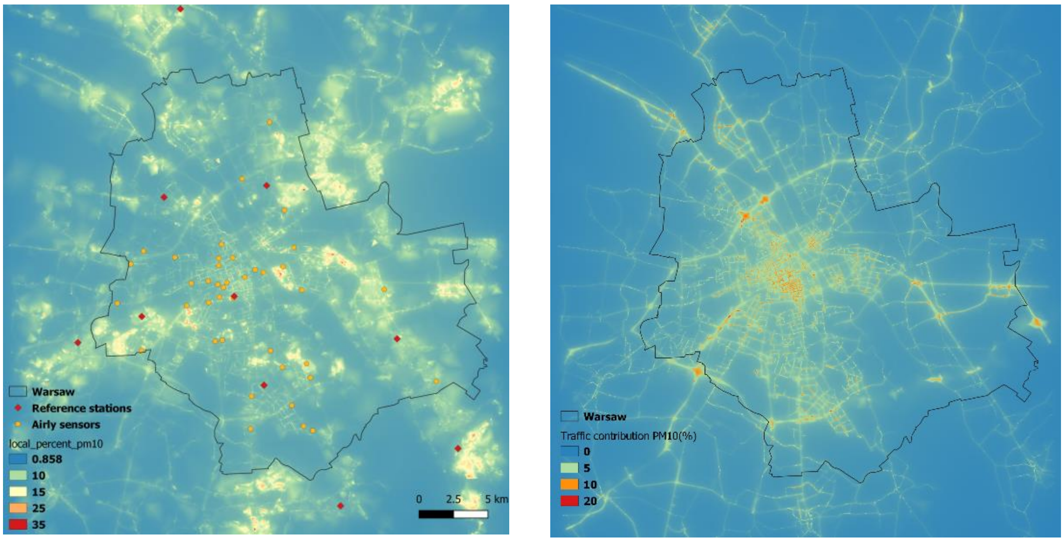

Figure 5- Annual average PM10 concentration (%) of (left) local contribution and of (right) traffic sector from ATMO-Street model – the location of the reference stations marked with red and Airly sensors with orange

The influence of Meteorological factors

Wind and temperature modelled data for January were compared with observation data provided by the Institute of Meteorology and Water Management (Figure 6). Our analysis found that high pollution periods corresponded with very low wind speeds and temperatures, particularly noticeable from the 7th to the 14th of January, exhibiting lower temperatures compared to observations. These conditions increased heating demand, indicated by Heating Degree Days (HDD), leading to heightened residential emissions. Consequently, this resulted in the model overestimating concentrations compared to observations during this period and overall in January.

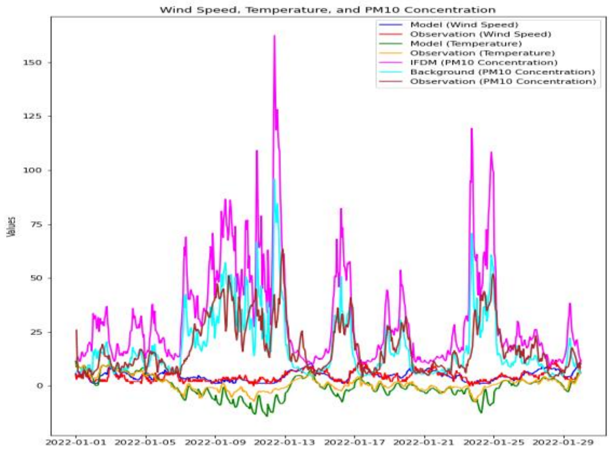

Figure 6. Comparison of the wind, temperature, and PM10 concentrations in January 2022

CONCLUSION

In this study, we developed a new model for the Warsaw area and nearby suburbs, combining detailed emission data from residential and traffic sources. We used a bottom-up approach, including exhaust, non-exhaust, and resuspension emissions. Background concentration data from the GEM-AQ model (2.5km resolution) were also integrated. Analysis showed discrepancies in PM10 and PM2.5 concentrations, with overestimation at background stations and underestimation at traffic stations. The model likely underestimated PM10 levels during dry months, raising questions about resuspension dynamics, especially in the OSPM framework. Our focus will now be on improving road dust estimation and evaluating OSPM's handling of resuspension.

Modeling urban environments at such high resolutions is challenging due to uncertainties in emission and meteorological data. Currently, residential emission inventories are quite unknown in Europe, making validation of these data challenging. Although our setup provided detailed residential emission calculations based on multiple parameters, hotspots were still observed, emphasizing the need to address uncertainties in emission inventories. Furthermore, we found that the residential sector contributes most to PM10 and PM2.5 concentrations during winter, while the traffic sector dominates during summer and warmer months.

REFERENCES

Berkowicz, R., 2000: Ospm-a parameterised street pollution model. *Environmental monitoring and assessment*, **65**, 323–331.

Gawuc, L., K. Szymankiewicz, D. Kawicka, E. Mielczarek, K. Marek, M. Soliwoda, J. Maciejewska, 2021: Bottom-up inventory of residential combustion emissions in Poland for national air quality modelling, current status and perspectives. *Atmosphere*, **12**, 1460.

Hooyberghs, H., S. De Craemer, W. Lefebvre, S. Vranckx, B. Maiheu, E. Trimpeneers, C. Vanpoucke, S. Janssen, F.J.R. Meysman, F. Fierens, 2022: Validation and optimization of the ATMO-Street air quality model chain by means of a large-scale citizen-science dataset. *Atmospheric Environment*, **272**, 118946.

Ibarra-Espinosa, S., R. Ynoue, S. O'Sullivan, E. Pebesma, M.d.F Andrade, M. Osses, 2018: Vein v0. 2.2: An R package for bottom-up vehicular emissions inventories. *Geoscientific Model Development*, **11**, 2209–2229.

Janssen, S., G. Dumont, F. Fierens, C. Mensink, 2008: Spatial interpolation of air pollution measurements using Corine land cover data. *Atmospheric Environment*, **42**, 4884–4903.

Kaminski, J., L. Neary, J. Struzewska, J. McConnell, A. Lupu, J. Jarosz, K. Toyota, S. Gong, J. Côté, X. Liu, 2008: Gem-aq, an on-line global multiscale chemical weather modelling system: model description and evaluation of gas phase chemistry processes. *Atmospheric chemistry and physics*, **8**, 3255–3281.

Lefebvre, W., F. Fierens, E. Trimpeneers, S. Janssen, K. Van de Vel, F. Deutsch, P. Viaene, J. Vankerkom, G. Dumont, C. Vanpoucke, 2011: Modeling the effects of a speed limit reduction on traffic-related elemental carbon (ec) concentrations and population exposure to ec. *Atmospheric Environment*, **45**, 197–207.

Lefebvre, W., M. Van Poppel, M., Maiheu, B., Janssen, S., and Dons, E. 2013: Evaluation of the RIO-IFDM-street canyon model chain. *Atmospheric Environment*, **77**, 325-337.